

# Dimensional Investigation of Corrugated Steel Silo with 4650 Tons Storage Capacity

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# Dimensional Investigation Of Corrugated Steel Silo With 4650 Tons Storage Capacity

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## 1. Introduction

Silo is widely used to store bulk material, such as grain, cement, powder, flavor and pharmaceutical products that experiences many types of loading in its operation cycle [1]. The silo wall was designed to anticipate buckling, which the strength is sensitive to the shape and geometric deviation [2]. Teng, et al [3] analyze the geometric imperfection of a welded steel silo. Their study was carried out by characterization of geometric imperfection in a full scale silo, as the base of shell buckling analysis in the real condition. The results show that the pattern of geometric imperfection correlates to the panels number of each shell. On the other side, there is a failure mode that depends on the fabrication process of its structure.

On the dimensional measurement of silos, Ding et al [4] develop a new technique to measure the silo surface. In his method, the observation data was combined in least-squares adjustment model. Then, the wall imperfection of silos was analyzed by double Fourier series to determine the dominant imperfection model. On its operational cycle, the silo wall is loaded by the radial force of stored grains. Goodey [5] shows that the pressure distribution of silo in horizontal direction follows hyperbolic function. While in vertical direction, the pressure distribution depends on the high and the relative stiffness of the grains and the silo wall. Shear stress that occurs at the interface



between wall and granular material causes a wall arching [6].

Prediction of the pressure at silo wall is based on the force balance on horizontal cross section caused by the stored grains [7] and the assumption of the lateral pressure ratio number (mean pressure ratio on wall which caused by the vertical stress in granular solid in various levels) [8-10]. Therefore, the deformation of a silo wall depends on the stiffness of the structure.

Ideally, the deformation pattern of silo wall is symmetric toward to the axis. However, due to the wall stiffness and connection among wall panels is not uniformly distributed, the asymmetric deformation is occurred. This paper presents measurement method of a silo wall by using a portable LDM in order to analyze the effect of silo capacity on the wall deformation. By measuring the roundness of the silo, an asymmetric pattern of the wall at 0% and 100% loading capacity are investigated. The diameter and height of the observed silo are 19000 mm and 20000 mm respectively, with the 100% loading capacity is 4650 tons of wheat grains.

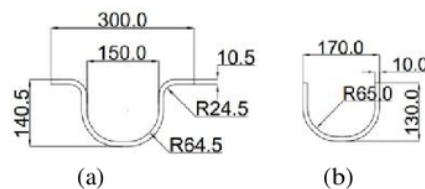
## 2. Experimental Methods

### A. Laser Distance Meter (LDM)

The dimension of the silo was measured using a portable LDM. The specification of the equipment is shown in Table 1. The display of LDM are the distance and the orientation based on horizontal axis.

**Table 1.** Specification Of The LDM

Accuracy	±0.04 in
Max. measuring distance	328 ft
IP protection class	IP 65 (EN 60529)
Operating temperature range	14 - 122 °F
Dimensions (L x W x H)	5.1 x 2.4 x 1.1 in
Weight with batteries	0.4 lb



**Figure 2.** a. Geometric of stiffener installed up to 3 m of height, b. Geometric of stiffener installed higher than 3 m

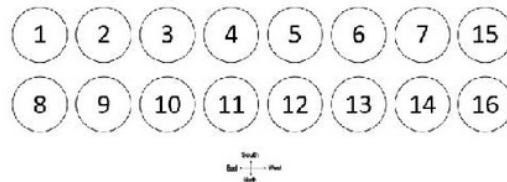
The silo wall is made from corrugated galvanized steel panels with the thickness is 2.5 mm. The dimension of panel is 3000 x 1100 mm. The profile of the wall is shown in Fig. 3, which 38 pieces of M12 bolts are used to joint among wall panels arranged in parallel, with the dimension of the overlap area is 1100 x 95 mm. The arrangement of bolts on the overlap area of silo wall is shown in Fig. 4.



**Figure 3.** The wall profile of corrugated steel panel

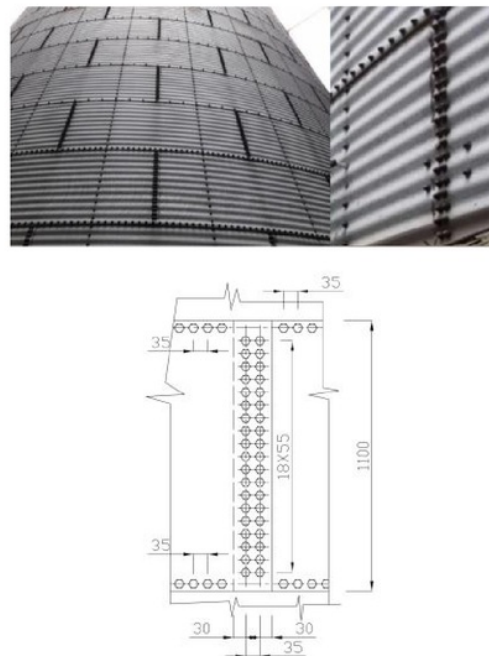
## B. Silo Structure

At the plant, 16 units of silos are installed on the single foundation with the formation is presented in Fig 1. The capacity of each silo is 4650 tons of wheat grains with the diameter and height are 19000 mm and 20000 mm, respectively. Dimensional measuring was performed on silo number 13.



**Figure 4.** Formation of silos

The observed silo is constructed using corrugated steel panels bolted to the stiffeners. Among panels as well as between stiffener and wall panel are joined using bolt connection. There are 40 stiffeners, which are installed in the inner silo. The dimension of the stiffener is illustrated in Fig. 5. The connection between wall and stiffener uses M10 bolt arranged in line formation with the spacing 100 mm.



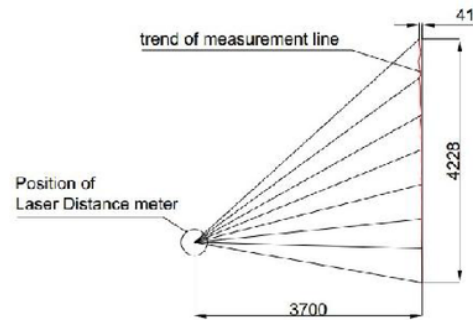
**Figure 5.** Bolts formation of the silo wall panels

### C. Calibration

Calibration of LDM was aimed to obtain the correction number at various height positions. The calibration steps are explained as follows:

- Fixed the position of measured bar in vertical installation
- Install the portable LDM in fixed horizontally position, 3700 mm from measured bar
- Measuring distance for each unit measurement line on the bar
- Plotting the data using a computer drawing program
- Extrapolate end points of each lines to compose the measurement pattern line
- Determine the correction value for the various heights

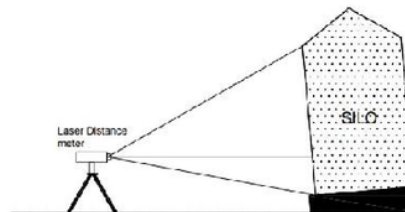
The calibration results show that the calibration number tends to slope in direction of the LDM position. By varying the relative position of LDM from measured bar (the variation are 2500 mm and 3700 mm), the maximum horizontal error is constant in around 41 mm at the height of 4228 mm (Fig. 6).



**Figure 5.** Calibration pattern line (red)

### D. Measurement procedure

Measurement process was performed at 4 directions with the distance between LDM and silo is 8 m by varying angles and loading capacity, i.e. 0% and 100% of loading capacities (see Fig. 6). The collected data is distance and its orientation. This data was plotted using a computer drawing program.



**Figure 6.** Measurement procedure of surface profile

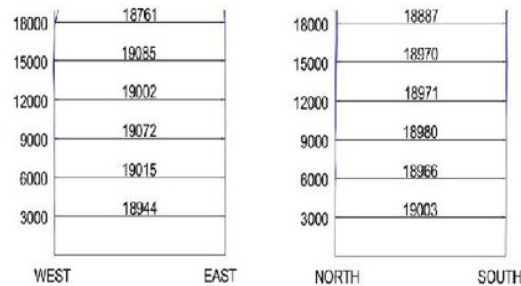
### E. Data processing

The calibration number was used to compensate the horizontal position of the end line, then the extrapolation of the end lines represented the measured surface profile of the silo. The roundness interpretation was obtained by connecting among data as a function of the radial position in the certain vertical position.

### 3. Result and Discussion

#### A. Dimensional silo at 0% loading capacity

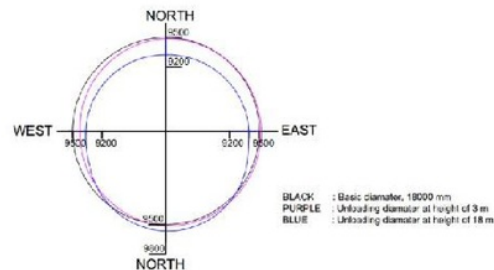
Plotting of measured data is used to represent the segmentation slope of the silo wall. At the height 15000 mm, the maximum slope on west and south orientation are 577 mm and 90 mm respectively. While, the surface profile of each measuring direction is shown in Fig. 7.



**Figure 7.** Surface profile measurement results of silo in four positions

The roundness profile of the silo wall is determined by plotting measuring data of four measuring positions at each height. Fig. 8 shows the roundness profile of silo wall by comparing between reference circle (black line) and the roundness profile on height of 3000 mm (purple) and 18000 mm (blue) respectively. The silo experienced the axis shifting and the roundness profile was inconsistent as a function of the height. The highest diameter of silo is the smallest diameter.

In structural point of view, the smaller diameter on higher position of the silo structure gives some advantages. Such as on loading cycle, the maximum deflection of the higher wall is never bigger than that of the lower diameter in vertical position. This is the one method to reduce the mixed load of silo wall particularly in gravitation direction.

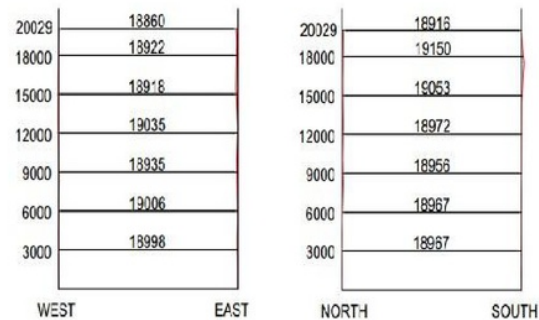


**Figure 8.** The roundness profile of silo wall on height 3000 mm (purple) and 18000 mm (blue) compared to the reference roundness profile

#### B. Dimensional silo at 100 % loading capacity

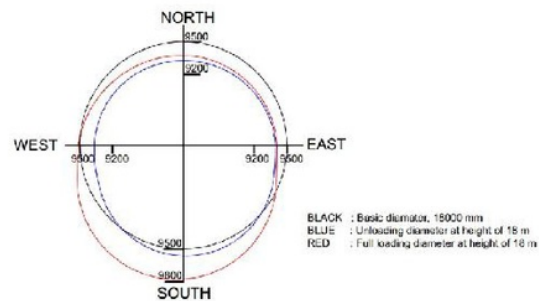
At 100% loading capacity (silo is filled 4650 tons of wheat grain), the wall profile is illustrated in Fig 9 for four measurement positions. The maximum deflection was around of 331 mm at height 18 m on south direction.



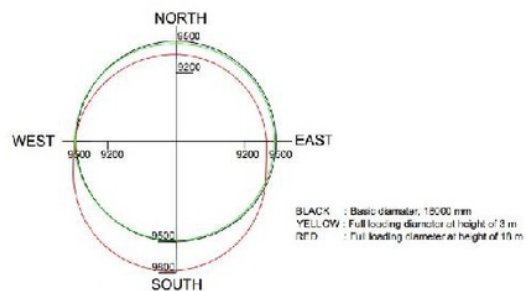


**Figure 9.** The external wall profile of silo on four measurement positions at 100 % loading capacity

Characteristic of silo structure can be investigated by comparing dimension of silo on loading-unloading condition. Fig. 10 shows the comparison of roundness profile of silo on 0% and 100% of loading capacity. On 100% loading capacity, the wall was not only to be bigger but also the silo axis is shifting (red line). On modular silo wall, which among wall panels is joined by bolt connection, the asymmetric deflection of the wall is particularly caused by the poor distribution of bolts tighten. When loaded with granular solid, a silo wall deformed according to the applicable radial force. On the inter-wall joints where the bolts were loose, the wall panels experienced a shift in position. In this condition the wall got the shear stress that occurs in the bolt hole. Fig 11. Shows that roundness of the silo wall in 100% loading capacity on vertical position of 3 m (green) and 18 m (red).



**Figure 10.** Roundness profile comparison when silo 0% loaded capacity (blue) and 100% loading capacity (red)



**Figure 11.** Comparison of the wall roundness at 3 m and 18 m of the vertical position on 100% loading capacity

#### **4. Conclusion**

In this paper, a new method for dimensional measurement of corrugated steel silo was performed, which is especially for determining the roundness of silo wall. Silo measurement was performed by a portable LDM so that the observation of dimensional condition of the silo can be simply performed. The measurement accuracy is strongly influenced by the calibration process, which is needed for calculating possible measurement errors that will occur. Measurement results show that the silo was in an asymmetric deformation condition. At the corrugated silo wall, which is jointed by bolt connection, the asymmetric deformation of the wall is related to the tighten level of connection bolts.



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